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Reverse-breaking CFS (rev-bCFS): Disentangling conscious and unconscious effects by measuring suppression and dominance times during continuous flash suppression

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ABSTRACT

Breaking continuous flash suppression (bCFS) is a widely used experimental paradigm that exploits detection tasks to measure the time an invisible stimulus requires to access awareness. One unresolved issue is whether differences in detection times reflect unconscious or conscious processing. To answer this question, here we introduce a novel approach (reverse-bCFS [rev-bCFS]) that measures the time an initially visible stimulus requires to be suppressed from awareness. Results from two experiments using face stimuli indicate that rev-bCFS can capture conscious effects, which indicates that contrasting standard bCFS with rev-bCFS can isolate unconscious processing occurring specifically during bCFS. For example, while face inversion impacted both bCFS and rev-bCFS, effects were larger in bCFS, suggesting a distinct contribution of unconscious processing to the advantage of upright over inverted faces in accessing awareness. Combining standard bCFS and rev-bCFS may offer a fruitful approach to disentangle conscious and unconscious effects occurring during interocular suppression.

1. Introduction

When our eyes are exposed to different images, conscious perception does not unify the two images in a unique percept but, rather, it dynamically alternates the two images. Such binocular rivalry (hereinafter BR) is useful for investigating which factors determine competition for visual awareness. Typically, stimuli that dominate perception for a longer time are believed to be consciously prioritized by the visual system (Alpers & Pauli, 2006), whereas those escaping suppression faster are thought to be unconsciously prioritized (Jiang et al., 2007), although this view is contested (Hesselmann & Moors, 2015; Moors, Hesselmann, Wagemans, & van Ee, 2017; Stein, Hebart, & Sterzer, 2011; Stein & Sterzer, 2014; Lanfranco et al., 2021). Over the past two decades, continuous flash suppression (CFS; Tsuchiya & Koch, 2005), a variant of BR, has been widely used to investigate visual processing outside awareness, that is, during suppression (Pournaghdali & Schwartz, 2020; Sterzer et al., 2014). In CFS, one eye is exposed to a high-contrast dynamic mask (typically updating at 10 Hz), which can suppress a lower-contrast stimulus shown to the other eye for prolonged periods, without the occurrence of perceptual alternations that characterize standard BR.

The so-called “breaking CFS” (bCFS; for reviews, see Gayet, Van der Stigchel, & Paffen, 2014; Stein, 2019; Stein, Hebart, & Sterzer, 2011) paradigm uses simple detection tasks to measure the time an initially suppressed stimulus needs to overcome suppression and

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access awareness, as it ramps up in contrast while the mask ramps down, so that the stimulus breaks suppression after a variable amount of time. The rationale is that CFS specifically disrupts conscious processing of the suppressed stimulus but may allow some stimulus information to be processed unconsciously and consequently influence the timing for conscious access. Thus, stimuli that are detected faster are thought to enjoy unconscious prioritization, boosting the sensory signal into consciousness. Differences in detection times in bCFS have been taken as evidence that a wide range of higher-level cognitive processes can occur unconsciously (for a review, see Hassin, 2013): facial and bodily features (Ciorli & Pia, 2023; Lanfranco, Rabagliati, & Carmel, 2023; Stein, Peelen, & Sterzer, 2011; Stein, Reeder, & Peelen, 2016; Stein, Sterzer, & Peelen, 2012), semantic content (Costello et al., 2009; Jiang et al., 2007; Kerr et al., 2017; Yang & Yeh, 2011), emotions (Hedger et al., 2015; Vetter et al., 2019; Yang et al., 2007; Zhan et al., 2015), degree of familiarity (Geng et al., 2012; Gobbini et al., 2013; Stein et al., 2014, 2016), threat (Gayet et al., 2016), multisensory information ((Aller, Giani, Conrad, Watanabe, & Noppeney, 2015; Zhou, Jiang, He, & Chen, 2010), food (Ciorli et al., 2024; Lee et al., 2022), and abstract concepts (Sklar et al., 2012). These results have challenged the conventional view according to which high-level processing during BR had been thought to be restricted to dominant phases only while having little influence on suppression times (Blake & Logothetis, 2002).

However, some have advocated caution on the validity of bCFS to reveal unconscious processing (Hesselmann & Moors, 2015; Moors, Hesselmann, Wagemans, & van Ee, 2017; Stein, 2019; Stein, Hebart, & Sterzer, 2011; Stein & Peelen, 2021; Stein & Sterzer, 2014; Lanfranco et al., 2021). Indeed, bCFS relies on responses to a subjectively *visible* stimulus, an approach in stark contrast with classic dissociation techniques in which unconscious processing is demonstrated when an *invisible* stimulus continues to influence behavior (Kouider & Dehaene, 2007; Schmidt & Vorberg, 2006). In bCFS, detection differences do not necessarily reflect unconscious processing under CFS but they could, alternatively, reflect differences in conscious stimulus processing of some image features during the transition into awareness, including differences in decision criteria (Moors et al., 2017). One common approach to exclude such conscious effects is to contrast bCFS with a non-CFS control condition, where the same stimuli are superimposed on the masks, thus not inducing interocular suppression. Most studies did not find bCFS-like detection effects in non-CFS control conditions (e.g., Costello et al., 2009; Jiang et al., 2007; Mudrik et al., 2011; Zhou et al., 2010); for a review, see Stein, 2019), which has been taken as evidence that bCFS effects must have reflected unconscious processing under CFS.

However, it has become increasingly clear that non-CFS control conditions are not suitable to control for conscious effects. First, empirical results indicate that they are not sensitive enough to pick up effects that many other psychophysical procedures reliably reveal, such as the face inversion effect. Second, non-CFS control conditions are perceptually vastly different from the CFS-like interocular dynamics characterized by perceptual uncertainty, and unpredictability of target appearance. With greater uncertainty, differences in decision criteria could have a larger effect on differences in detection times, and thus spuriously amplify bCFS effects. As mimicking CFS-induced perceptual uncertainty without interocular suppression is extremely difficult to achieve, one solution would be a control condition that captures conscious effects but also involves interocular suppression.

1.1. *The reverse-breaking CFS proposal*

Here, we introduce “reverse-breaking continuous flash suppression” (hereinafter, rev-bCFS), which reverses the standard bCFS trial sequence. Specifically, at the beginning of a trial the high-contrast target stimulus is consciously perceived before it is gradually suppressed by the mask, as stimulus contrast is ramped down while the mask’s contrast ramps up until the mask fully suppresses the target. Participants press a key as soon the last cue of the stimulus disappears from awareness (contrasting with standard bCFS where participants detect target appearance). In other words, rev-bCFS measures the time it takes for a stimulus to be suppressed (i.e., the transition from conscious to unconscious, or conscious disappearance) – that is, how long it persists and dominates conscious perception, as compared to bCFS that measures the time it takes for a stimulus to overcome suppression (i.e., the transition from unconscious to conscious). Since both methods rely on interocular suppression dynamics, bCFS and rev-bCFS may be better comparable than bCFS and standard non-CFS control conditions. The key difference lies in the type of information processing occurring before the response: bCFS involves potentially unconscious processing before the subjective visibility threshold for the unconscious-to-conscious transition is crossed, whereas rev-bCFS entails conscious processing preceding the threshold for the conscious-to-unconscious transition. The comparison of bCFS vs. rev-bCFS could thus allow to measure and control the contribution of conscious effects to bCFS detection differences.

We tested this approach in two experiments using face stimuli. In Experiment 1, we compared the well-established face inversion effect (FIE) between bCFS and rev-bCFS. The FIE reflects the visual system’s enhanced sensitivity to process faces with an upright (i.e., in their prototypical spatial representation) compared to an inverted (i.e., rotated by 180°) orientation. In addition to bCFS, better detection of upright faces has been observed in a wide variety of tasks, including visual search, attentional blink, and backward masking (Garrido et al., 2008; Lewis & Edmonds, 2003; Lewis & Edmonds, 2005; Rossion et al., 1999; Tyler & Chen, 2006; Van Belle et al., 2015), but, curiously, typically not in the classic non-CFS control condition (e.g., Jiang, Costello, & He, 2007; Zhou, Zhang, Liu, Yang, & Qu, 2010, but see Stein et al., 2011). We considered the FIE as a candidate for an effect that may involve conscious and unconscious mechanisms, as it occur both during conscious (e.g., Engel, 1956) and unconscious (e.g., Stein & Peelen, 2021) processing. A larger effect in bCFS than in rev-bCFS would thus provide tentative evidence for unconscious face processing contributing to the FIE detection effect in bCFS. In Experiment 2, we tested how the recognizability of Mooney-like face stimuli influenced bCFS and rev-bCFS. Previous studies showed that attributing a specific meaning to a visual stimulus (compared to the same stimulus without such meaningful content and acquired perceptual structure) leads to an increase in perceptual dominance in a BR task (Yu & Blake, 1992). In a pre-post design, we tested detection effects for two-tone degraded face stimuli (i.e., Mooney faces; Latinus & Taylor, 2005; Schwiedrzik et al., 2018) in participants initially not aware of them being faces (pre-meaning reveal), but being informed about their meaning later (post-meaning reveal – experimental group), as compared to participants not subjected to the pre-post reveal (control group). To prevent Mooney faces from being recognized as faces before revealing their meaning, we inverted the stimuli (George et al., 2005). Thus, the experimental group performed the bCFS and rev-bCFS tasks with inverted Mooney faces without knowing they represented face stimuli, and stimulus meaning was revealed by temporarily turning them upright in the pre-post meaning reveal phase. Following the meaning-reveal phase, participants were able to recognize them as faces even when inverted. The bCFS and rev-bCFS tasks were subsequently repeated with inverted Mooney faces, with the experimental group only now being able to recognize them as faces, whereas the control group had been subjected to the meaning reveal before any tasks, controlling for any pre-post difference between the tasks. We hypothesized the effect of stimulus recognition to involve conscious rather than unconscious processing, and thus slower disappearance timings in rev-bCFS for the group subjected to the pre-post reveal, but no effects in bCFS.

2. Materials and methods

2.1. Experiment 1

2.1.1. Participants

21 subjects (eight female, 26.5 ± 2.2 years old) were recruited for the study. They had normal or corrected-to-normal vision, no

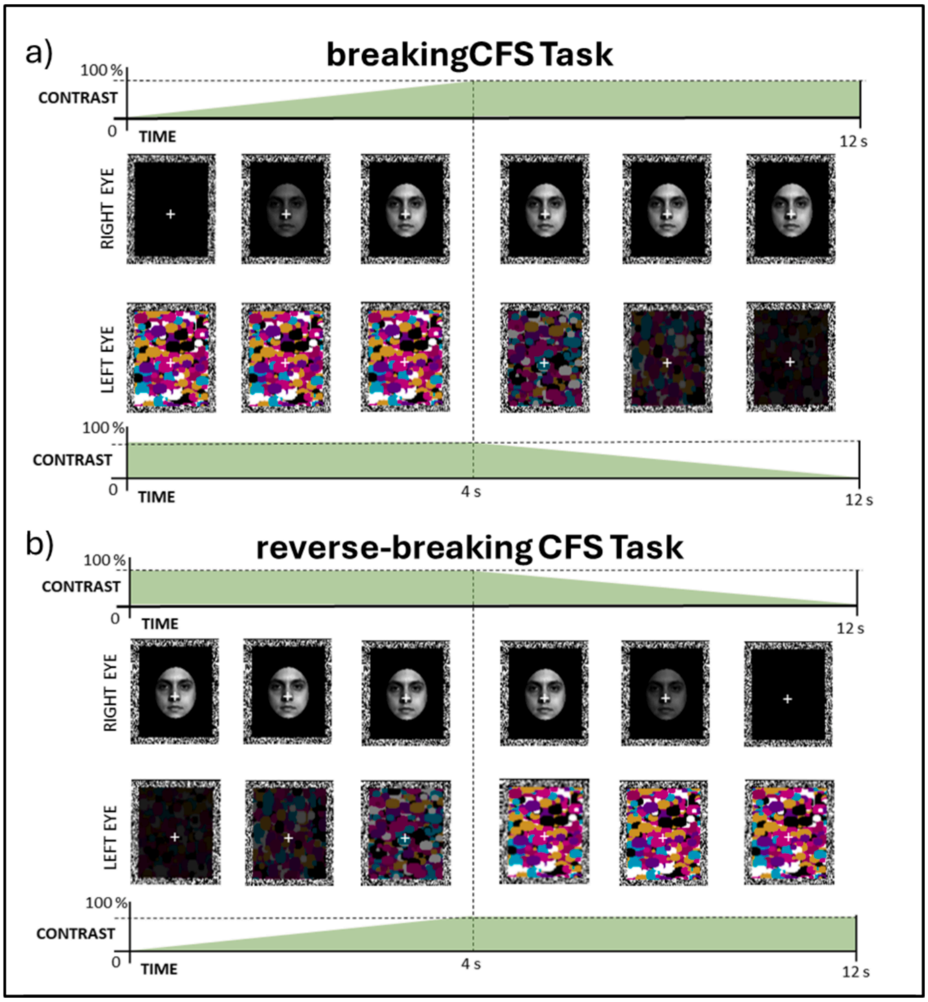

Fig. 1. *Schematic representation of the two tasks. a) bCFS*: After 2.1 s of inter-trial interval, a high-contrast mask (10 Hz) was shown to one eye, and its contrast was decreased from 100 to 0% within 8 s after 4 s of trial. The target face was shown to the other eye, and its contrast was increased from 0 to 100% within the first 4 s of the trial. Each trial lasted for a maximum of 12 s or until response (space bar) once participants detected the first cue of the target breaking the suppression. *b) rev-bCFS*; the target face, shown to one eye, was shown at full visibility in the first 4 s of the trial, then its contrast was linearly decreased from 100 to 0% in the remaining 8 s. On the other eye, the mask increased its contrast from 0 to 100% within the first 4 s of the trial and remained stable until the end of the trial (12 s) or until response. Participants had to press the space bar once the last cue of the target disappeared from their conscious percept.

history of neurological diseases, and they were naïve concerning the research question. The sample size was estimated with a priori power analysis based on the FIE effect size $d = 0.92$ reported by Jiang and colleagues (2007). With such an effect size, for a one-tailed t-test with $alpha = 0.05$ and 99 % power, the estimated sample size was 21 subjects. The study was approved by the Ethical Committee of the University of Turin (protocol n. 0486683), and participants gave informed consent to participate in the study.

2.1.2. *Apparatus, stimuli, and procedure*

The experiments were programmed in Matlab (Release 2021b) using the Psychtoolbox (Brainard, 1997) functions and presented on a Q-BenX monitor (1920 x 1080 pixels resolution, 120 Hz refresh rate). Participants sat in front of the screen at approximately 57 cm and in front of a chinrest with a built-in stereoscope that was adjusted for each participant to allow for stable binocular vision. The screen background was black, and two fusion squares (1.50° x 1.95°) with black and white pixel contours (0.15°) were used for the binocular presentation of the stimuli. Stimuli (1.50° x 1.95°) consisted of 40 grayscale faces (with neutral expression, half males and half females), matched in luminance and contrast, and cropped into oval shapes (Stein et al., 2017). High-contrast colorful masks were generated in Matlab. The order of the two tasks (bCFS and rev-bCFS) was counterbalanced across participants.

Breaking continuous flash suppression (bCFS) task.

During the trial, one eye was exposed to a target face that was linearly ramped up in its contrast from 0 to 100% within the first 4 s of the trial and then remained constant until the end of the trial, while the other eye was exposed to a dynamic high-contrast mask flashing at 10 Hz of frequency. Mask contrast was 100% during the first 4 s of the trial, then its contrast linearly decreased from 100 to 0 % in the remaining 8 s. Thus, each trial lasted for a maximum of 12 s, or until a response was made (Fig. 1*a*). Targets and masks covered the fusion squares, with the target being presented in the center. Participants were asked to maintain fixation to the central fixation cross, to avoid blinks during the trial, and to keep both eyes open during the experiment. Importantly, they were instructed to press the space bar as soon as they perceived any part of the target breaking suppression (i.e., when anything other than the mask became visible). They were instructed not to wait until they could identify the target image. Trials were separated by 2.1 s of inter-trial interval, and the task was composed of 160 randomized trials, with 80 trials containing upright face targets, and 80 trials containing their inverted counterparts (i.e., rotated by 180°). The target eye was also counterbalanced and randomized (in 80 trials the face was shown to the right eye and in the remaining 80 to the left eye). After 12 trials of familiarization, the experiment began and lasted approximately 15 min, with a small break after 80 trials.

Reverse-breaking continuous flash suppression *(rev-bCFS) task.*

The setup for the rev-bCFS task was almost identical to the bCFS task, with two main critical differences. First, contrast ramping phases were reversed: the target face started with 100% contrast for the first 4 s of the trial and then decreased linearly from 100 to 0% over the next 8 s, while the masks started with 0% contrast and increased to 100% within the first 4 s, remaining constant until response or the end of the trial (12 s; see Fig. 1*b* for a schematic representation). Participants were asked to respond as quickly as possible to the disappearance of the target by pressing the space bar when the last part of the face became invisible.

2.1.3. *Statistical analysis*

One participant reported unstable binocular perception and was excluded from the analysis. In the bCFS task, trials with response times lower than 300 ms (0.4% of the trials) were excluded (as this suggested that stimuli were not suppressed). As bCFS data can be subjected to different metrics, we decided to use the most typical analysis approaches applied to such task (i.e., raw median data, log-transformed data, latency-normalized data) to have a comprehensive metrical assessment to validate our methodology. To remove between-subjects variability that typically affects bCFS performance and is of no interest for the effect of the experimental manipulation, we used the latency-normalization approach that has been used in other studies (Gayet et al., 2016; Gayet & Stein, 2017; Tsuchiya et al., 2006). This index has been shown account for between-subject variability and to approximate RT differences to a normal distribution, similar to logarithmic transformations (that we also calculated), and to enhance RT differences caused by the experimental manipulation by reducing type II error rate. Parameters were calculated as in the work by Gayet and Stein (Gayet & Stein, 2017). The latency-normalized RT difference was thus scored as follows:

$$\Delta RT_{NORMALIZED} = 100 * \frac{(RT_{UPRIGHT} - RT_{INVERTED})}{(RT_{OVERALL})}$$

where $RT_{UPRIGHT}$ was defined as the median value of the upright condition, $RT_{INVERTED}$ as the median value of the inverted condition, $RT_{OVERALL}$ as the median RT's average within each condition. Medians were used to account for the skewed distribution of the raw data. This index was calculated for the two tasks separately. Negative values indicate faster RT for upright faces. Another normalized FIE index was calculated after log-transforming the raw RTs:

$$\Delta RT_{LOG-TRANSFORMED} = log10(RT_{UPRIGHT}) - log10(RT_{INVERTED})$$

Planned t-test comparisons, analyzing differences between upright and inverted faces within each experiment, and comparing the face-inversion differences between the two experiments were conducted with JASP (JASP Team, 2016).

2.2. *Results*

Breaking CFS task. Median RTs were faster for upright (M = 3.09 s, SE = ±0.27) than for inverted faces (M = 3.77, SE = ± 0.30), resulting in a face-inversion effect of 678 ms. This difference was statistically significant for both median RTs ($t_{(19)} = -4.22$, $p < 0.001$, Cohen’s $d = 0.94$) and log-transformed RTs ($t_{(19)} = -4.32$, $p < 0.001$, one-tailed, Cohen’s $d = 0.96$), indicating faster access to awareness for upright than for inverted faces. The negative latency-normalized index showed that upright face condition sped up RTs by 21.2% (SE = ±4.8%). Thus, we replicated the standard FIE obtained in bCFS (raw difference = -678 ms, SE = ± 0.16) with an effect size (Cohen’s $d = 0.94$) in line with other studies (Gayet & Stein, 2017; Jiang et al., 2007; Stein et al., 2016).

Reverse-breaking CFS task. Median RTs for face disappearance from awareness were 2.52 s (SE = ± 0.19), whereas upright median RTs were 2.63 s (SE = ±0.19), and 2.40 s (SE = ±0.06) for inverted exemplars. The face-inversion difference was 223 ms (SE = ±0.05). Data were normally distributed. Planned *t*-test comparison showed a significant difference between the two conditions in both raw ($t_{(19)} = 4.35$, $p < 0.001$, Cohen’s $d = 0.97$) and log-transformed ($t_{(19)} = 3.40$, $p = 0.002$, Cohen’s $d = 0.76$) data, with consistent effect sizes. These results indicate that upright faces, as compared to inverted ones, were slower in disappearing from awareness. The latency-normalization index was positive, showing that upright faces slowed down overall RTs by 9.9% (SE = ±2.8%).

Task comparison. We then compared the overall median RTs for faces within the two tasks. Overall RTs were longer in bCFS ($t_{(19)} = 2.36$, $p = 0.029$, Cohen’s $d = 0.53$), showing that suppression was faster than breaking suppression. Next, we compared the face inversion effect between the two tasks. As the face inversion effect in bCFS and rev-bCFS have opposite signs (i.e., faster RTs in bCFS and slower RTs in rev-bCFS, both indicating upright face prioritization), we reversed the bCFS FIE sign. The analysis revealed consistent results across the different metrics used, showing that the FIE was larger for bCFS compared to re-bCFS with raw median RTs ($t_{(19)} = 2.51$, $p = 0.011$, Cohen’s $d = 0.56$; Fig. 2*a*), log-transformed RTs ($t(19) = 1.89$, $p = 0.037$, Cohen’s $d = 0.42$; Fig. 2*b*), and latency-normalized effects ($t(19) = 1.91$, $p = 0.036$, Cohen’s $d = 0.43$; Fig. 2*c*).

2.3. Experiment 2

2.3.1. Participants

Fifty subjects (28 female, mean age 24.9 ± 3.5 years old) with normal or corrected-to-normal vision and without previous history of neurological diseases were recruited for the study. The sample size was estimated with an a priori power analysis (through g*Power) based on a medium effect size ($f = 0.25$) for a repeated measures ANOVA with between-within interactions for 2 groups, alpha = 0.05, and statistical power of 99%, resulting in 50 subjects. The study was approved by the Ethical Committee of the University of Turin (protocol n. 0486683), and Participants gave informed consent to participate in the study.

2.3.2. Apparatus, stimuli, and procedure

Apparatus and task structure were identical to Experiment 1, except for the following changes. The two stimuli were an inverted exemplar of a two-tone “Mooney” face and a neutral and meaningless two-tone image (both 1.5° x 1.95°, see Fig. 3*c*). Verbal and written instructions for the two tasks (bCFS and rev-bCFS, as in Experiment 1) were provided to participants, who were then exposed to the two stimuli. The experimental group (N = 25) was told that they had to detect appearance and disappearance of the stimuli, and they performed one bCFS and one rev-bCFS blocks (counterbalanced) made of 36 trials each (18 each stimulus). After they completed the two blocks, they were told that one stimulus was an inverted face (pre/post meaning-reveal). The stimulus was then rotated by 180° (turning it upright) until participants recognized the face, and rotated again, making sure that participants could still see the face while inverted. The same exposure time was dedicated to the neutral stimulus, and we asked whether they could have perceived a meaning (all participants said no). After the meaning was revealed, they performed the two tasks again (counterbalanced). For the control group (N = 25), the procedure was the same, with the exception that the meaning reveals occurred before performing any block. As a control manipulation, we decided to expose participants to stimulus reveal before beginning the experiment (rather than not exposing them at all) to prevent spontaneous Mooney face recognition in a naive control group during the experiment.

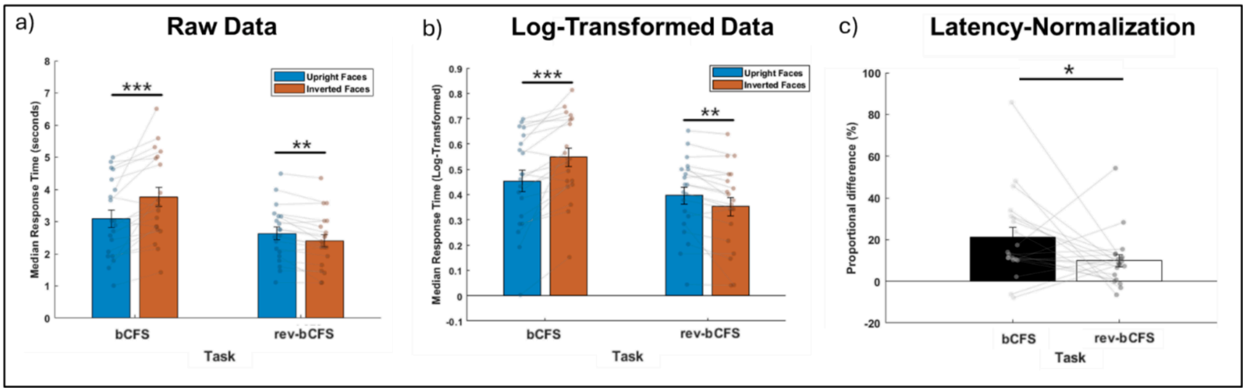

Fig. 2. *Results of Experiment 1. a*) shows median RTs, whereas *b*) shows median log-transformed RTs (and standard errors) from the bCFS task as a function of face orientation, reflecting the suppression time of the targets, and from the rev-bCFS task, reflecting face disappearance/dominance. *c*) shows the comparison of FIE across the two tasks with the latency-normalization procedure (and SE). Points represent subject-based performance *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

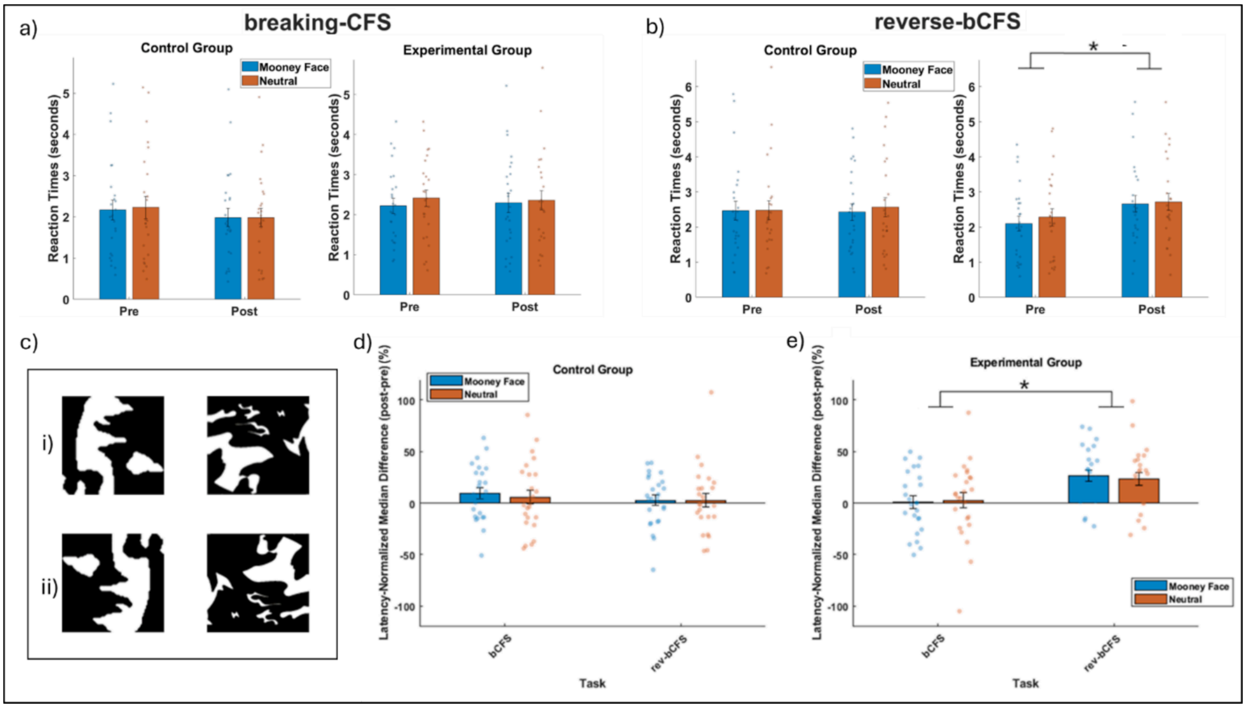

Fig. 3. *Results of Experiment 2. a*) and *b*) show median RTs for the control and the experimental group within the bCFS (*a*) and the rev-bCFS (*b*) tasks (with subject-based data points and SE). *c*) shows the targets of Experiment 2; i) represents the stimuli used in the two tasks, a two-tone inverted Mooney face and a two-tone neutral stimulus (i.e., random white shapes on a black background without any meaningful structure), whereas ii) represents the stimuli meaning reveal (same stimuli rotated by 180°), with participants recognizing the Mooney Face, which was rotated again for the post-tasks in the Experimental group, for the entire experiment in the control group. The same reveal time was dedicated to the neutral stimulus. *d*) and *e*) show the Latency-Normalized indices (post minus pre) in control (*d*) and experimental (*e*) participants, with subjects' data-points and SE. $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

2.3.3. Statistical analysis

In the bCFS task, trials with response time lower than 300 ms (0.3% of the trials) were excluded. We used the latency-normalization indices as in Experiment 1 by subtracting post blocks from pre blocks measures separately for each stimulus and task. The latency-normalized median differences were thus scored as follows:

$$\Delta RT_{NORMALIZED} = 100 * \frac{(RT_{POST} - RT_{PRE})}{(RT_{OVERALL})}$$

resulting in four measures (bCFS/rev-bCFS tasks, Mooney/Neutral stimuli). Negative scores indicate faster RT for stimuli presented in the post-reveal block. For task comparison, given that prioritization in bCFS and in rev-bCFS have opposite signs (i.e., faster RTs in bCFS and slower RTs in rev-bCFS), we flipped the sign for the bCFS latency normalized index.

2.4. Results

Breaking CFS task. A repeated measures ANOVA was performed with the within-subject factor *Stimuli* (Mooney Face, Neutral) and the between-subject factor *Group* (Experimental, Control) on the latency normalized median differences. No significant effects were found, indicating that neither the stimulus nor the reveal manipulation or their interaction affected conscious access in post- vs. pre-reveal ($p > 0.05$; see Fig. 3*d and 3e*). Equivalent results were found with median (see Fig. 3*a*) and log-transformed RTs.

Reverse-breaking CFS task. The same statistics were applied to latency-normalized differences from the rev-bCFS task. Results revealed a main effect of *Group* ($F_{(1,48)} = 9.29$, $p = 0.004$, $\eta_p^2 = 0.16$), and *t*-test post-hoc comparisons showed that in the experimental group both stimuli (Mooney face and Neutral stimulus) persisted longer in visual awareness in post- vs. pre-reveal ($t_{(48)} = -3.05$, $p = 0.004$, Cohen's $d = 0.77$; see Fig. 3*d and 3e*). No other significant effects were found ($p > 0.05$). Similar results were confirmed with log-transformed ($t_{(48)} = -3.04$, $p = 0.004$, Cohen's $d = 0.78$) and raw differences ($t_{(48)} = -2.35$, $p = 0.023$, Cohen's $d = 0.58$; see Fig. 3*b*).

Task comparison. The two tasks were directly compared with a repeated measures ANOVA with the within factors *Stimuli* (Mooney Face, Neutral), *Task* (bCFS, rev-bCFS) and the between factor *Group* (Experimental, Control) for latency normalized differences. Results showed a significant interaction between *Group*Task* ($F_{(1,48)} = 6.14$, $p = 0.017$, $\eta_p^2 = 0.11$; see Fig. 3*d and 3e*). No other significant effects were found. Post-hoc *t*-test comparisons revealed that only the Experimental group showed longer persistence of both stimuli in the rev-bCFS only ($t_{(48)}$ = -3.05, p = 0.004, Cohen's d = 0.77).

3. Discussion

We introduced reverse-breaking continuous flash suppression (rev-bCFS) as a novel approach to measure and control for conscious influences on suppression times recorded with the popular breaking continuous flash suppression (bCFS) paradigm. In two experiments using face stimuli we sought to disentangle conscious and unconscious influences on detection effects by comparing conscious access (bCFS) and disappearance (rev-bCFS) using face stimuli. Specifically, we tested the face inversion effect (FIE; Experiment 1) and the effect of stimulus recognizability using two-tone Mooney-like stimuli (Experiment 2). Based on the assumption that rev-bCFS captures conscious effects, we reasoned that detection effects that are larger in standard bCFS than in rev-bCFS would reflect an additional contribution of unconscious processing occurring during suppression. Indeed, in Experiment 1 we found that the FIE was greater in bCFS than in rev-bCFS, suggesting that unconscious processing contributed to the advantage of upright over inverted faces in accessing awareness. In Experiment 2, we found that assigning a meaning to two-tone stimuli slowed disappearance timings in rev-bCFS but had no effect on bCFS. This effect was not specific to two-tone Mooney-like faces, but similarly present for a meaningless neutral two-tone stimulus, indicating that the effect was possibly driven by top-down attention affecting conscious but not unconscious processing.

The greater FIE in bCFS suggests that there is a contribution of unconscious processing to the effect in bCFS that is absent in rev-bCFS. The putative neural mechanisms underlying such processing are still partially unclear; whereas some findings highlight the role of a subcortical pathway for fast and coarse face processing (Stein et al., 2011; Zhou et al., 2010), others highlighted the importance of extrastriate cortical activity in the FFA for the FIE (Yovel & Kanwisher, 2005) that can survive interocular suppression, albeit much reduced compared to visible conditions (Jiang & He, 2006). Such preferential processing of upright faces has been hypothesized to reflect an innate perceptual predisposition for faces, being present at early stages of the lifespan (Farroni et al., 2005; McKone, Kanwisher, & Duchaine, 2007; Stein, Peelen, & Sterzer, 2011), as well as effects of visual familiarity acquired during the lifespan (Laguesse et al., 2012; Stein et al., 2014).

The results of Experiment 2 were quite different: an effect of revealing stimulus meaning was observed only in the rev-bCFS task, where participants who were informed about the Mooney face stimulus meaning (the experimental group) subsequently exhibited slower disappearance timings. Our initial hypothesis was that acquired knowledge of stimulus meaning would influence conscious but not unconscious stimulus processing (Yu & Blake, 1992). However, this effect was not specific to the two-tone face stimulus but was similarly observed for the meaningless two-tone neutral stimulus. This challenges the prior knowledge hypothesis, as it would not predict the effect on the neutral stimulus within the experimental group. One possibility is that participants generally allocated more top-down attention, potentially attempting to discern whether the presented stimulus was the face or the neutral image, thus providing both stimuli with an attentional boost. Indeed, attention has been shown to influence dominance phases of stimuli in BR (Chong & Blake, 2006; Mitchell et al., 2004; Paffen & Alais, 2011; van Ee et al., 2005). Crucially, this effect was absent in the bCFS task, suggesting that it involved conscious mechanisms of top-down attention but no unconscious processing occurring under suppression. Alternatively, the effect could have been driven by prior knowledge of stimulus meaning per se, assuming that the neutral stimulus acquired the "meaning" of being the neutral, meaningless stimulus. Higher-level visual areas, grouping the stimulus in a coherent, structured, and meaningful representation, might subsequently influence activity in lower-level areas through top-down feedback projections (Bar et al., 2006; Murray et al., 2006), boosting perceptual dominance (Tong et al., 2006) but, crucially, not suppression times. Indeed, for consistency, the neutral stimulus was also shown to participants of the experimental group during the pre-post reveal for the same amount of time as the Mooney face (even though it was demonstrated to them that inverting the neutral stimulus did not reveal any meaningful structure). Following this hypothesis, our results show that prior knowledge and stimulus meaningfulness influence conscious, but not unconscious, visual processing during CFS.

We suggest that rev-bCFS could represent an improvement over standard non-CFS control conditions, given that bCFS and rev-bCFS share interocular suppression, similar perceptual dynamics, uncertainty, and require a similar detection task around the subjective threshold to awareness. Recently and independently from the present work, a similar approach has been used, measuring appearance from suppression and disappearance from dominance for different image categories (e.g., faces vs. objects) during CFS in a continuous cycle (Alais et al., 2024). These authors found that differences between images categories (e.g., faces requiring lower contrast to appear and to disappear than objects) were similar for appearance and disappearance. In line with our logic here, this was interpreted as showing that high-level stimulus properties such as category membership do not influence suppression. These findings appear inconsistent with standard hybrid models of binocular rivalry that postulate both low-level and high-level stimulus effects on suppression (Hesse & Tsao, 2020; Tong et al., 2006), as well as with our observation of a larger FIE during bCFS than rev-bCFS, which suggests an effect of configural stimulus properties on suppression. Although binocular rivalry and CFS involve different suppression depths and might not be directly comparable, there is (debated) evidence that both low-level and high-level processing may occur under CFS (for reviews, see Hassin, 2013; Hesselmann & Moors, 2015; Moors et al., 2017; Sklar et al., 2018; Stein, 2019). One reason for this apparent discrepancy is that, although Alais and colleagues (2024) carefully matched certain low-level properties of their stimuli, they compared the ratio of stimulus breakthrough to disappearance (i.e., suppression depths) across distinct image categories. Interpreting detection differences of target stimuli that are physically different during CFS is challenging (Stein, 2019). Here, we compared physically identical stimuli, changing only their spatial orientation (Experiment 1) or their ascribed meaning (Experiment 2). In addition, the continuous presentation cycle employed in this previous study may have resulted in adaptation and habituation effects as a consequence of the same stimulus being presented for an entire block of 60 or 120 s (while only modulating stimulus contrast). Such adaptation effects likely played less of a role in our comparison of bCFS and rev-bCFS using separate trials with much shorter presentation times and trial-wise stimulus randomization. Nevertheless, the two approaches share a common rationale: breakthrough timings alone are insufficient to conclusively infer differential unconscious processing. The comparison of suppression and breakthrough timings represents a significant advancement in RT-based CFS paradigms to better isolate CFS-specific unconscious processing. While the studies employed only slightly different methodologies based on this shared principle, they yielded intriguingly distinct results.

Before concluding, some cautionary notes are in order: we are not suggesting that the rev-bCFS paradigm can provide unequivocal evidence that unconscious processing differences contributed to detection effects. The present approach relies on the assumption that conscious and unconscious processes determine detection speed, and that rev-bCFS captures all conscious processes that could drive bCFS detection effects. If this assumption is not met, larger effects in bCFS may be driven by conscious factors other than those captured by rev-bCFS. To unequivocally establish that a detection effect was caused by unconscious factors, accuracy-based dissociation paradigms are required. For example, using backward masking, recent work (Stein & Peelen, 2021) measured detection differences (e.g., better detection of upright than inverted faces) while simultaneously ensuring that subjects had no access to the key manipulation driving these detection effects (e.g., they could not distinguish between upright and inverted faces). However, such accuracy-based dissociation approaches are challenging to combine with CFS, given its inter- and intraindividual variability, and unpredictability in strength and depth of suppression. Moreover, objective awareness measures such as those employed by Stein and Peelen (2021) may be too conservative and thus risk underestimating the extent of unconscious processing. The rev-bCFS paradigm, instead, relies on intuitively appealing subjective measures of awareness that aim to capture the subjective appearance and disappearance of contents in visual consciousness. Furthermore, although bCFS and rev-bCFS were matched in terms of their experimental and procedural structure (interocular suppression methods, stimuli, detection task on visibility threshold, timings of ramping contrasts, maximum trial length), it is possible that observers adopted different decision criteria for indicating target appearance and disappearance. In detection tasks, including those using CFS, differences in decision criteria can influence and potentially confound the measurement of differential detection thresholds (e.g., Stein et al., 2011; Stein & Peelen, 2021). The current RT-based method does not quantify these decision thresholds. Future studies may tackle the aforementioned methodoligcal challenges and use purely accuracy-based detection measures in the rev-bCFS paradigm to rule out differential detection criteria (e.g., Lanfranco et al., 2022; Stein & Peelen, 2021). Another limitation is that overall RTs for the two tasks differed. For that reason, we calculated effects using the latency-normalization procedure that accounts for overall variability in task-related RTs differences as well as for between-subject variability that usually characterizes RT-based interocular suppression paradigms (Gayet et al., 2016; Gayet & Stein, 2017; Stein et al., 2012; Stein et al., 2011; Tsuchiya et al., 2009). Finally, detection in bCFS and rev-bCFS might also be influenced by differences in the dynamics of stimulus contrast adjustments, as contrast ramping phases are reversed between the two tasks. As a result, the comparison of the two tasks could be influenced by differences in stimulus strengths.

Another advantage of rev-bCFS is that it can be used to measure conscious effects on the dynamics of interocular suppression that are not influenced by suppression times as in the classic BR alternation cycle. Indeed, in BR it cannot be estimated whether longer dominance times reflect prioritization during conscious perception or prioritization outside of awareness, with stimuli spending less time in the suppression phases. Thus, with BR it is difficult to disentangle the contribution of conscious and unconscious processing on visual awareness. Furthermore, dominance and suppression phases are known to rely on distinct brain mechanisms that can differentially affect interocular suppression timings (Blake & Logothetis, 2002), and BR and CFS are characterized by different depths of suppression (Tsuchiya et al., 2006) that render their comparison difficult. The combined use of bCFS and rev-bCFS could represent an improvement over BR to investigate dominance and suppression timings independently, as well as a useful tool to study differential brain dynamics for stimuli appearing and disappearing from awareness, possibly informing current theories on the neural correlates of consciousness (Seth & Bayne, 2022).

In conclusion, we introduced rev-bCFS as a practical and straightforward approach to control for conscious effects on detection measured with bCFS. The combination of bCFS and rev-bCFS may represent a promising experimental paradigm for disentangling conscious and unconscious influences on access to awareness and may better isolate unconscious processing than standard non-CFS control conditions. This approach may prove fruitful in future investigations testing the scope and limits of unconscious processing under interocular suppression.

CRediT authorship contribution statement

Tommaso Ciorli: Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Lorenzo Pia:** Writing – review & editing, Supervision, Resources, Conceptualization. **Timo Stein:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization.

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Data availability

Data will be made available on request.

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